Evidence for dark matter in the inner Milky Way...Really?

R. Durazo, X. Hernandez & S. Mendoza*
Instituto de Astronomía,
Universidad Nacional Autónoma de México,
AP 70-264, Distrito Federal 04510, México

(Dated: March 26, 2015)

The following is a comment on the recent letter by Iocco, Pato, and Bertone (2015) where the authors claim to have found "*...convincing proof of the existence of dark matter...*". The letter in question presents a compilation of recent rotation curve observations for the Milky Way, together with Newtonian rotation curve estimates based on recent baryonic matter distribution measurements. A mismatch between the former and the latter is then presented as "*evidence for dark matter*". Here we show that the reported discrepancy is the well known gravitational anomaly which consistently appears when dynamical accelerations approach the critical Milgrom acceleration $a_0 = 1.2 \times 10^{-10} \mathrm{m\,s^{-2}}$. Further, using a simple modified gravity force law, the baryonic models presented in Iocco, Pato, and Bertone (2015), yield dynamics consistent with the observed rotation values.

Keywords: Galactic Dynamics;Relativity and gravitation;Modified theories of gravity;Milky Way

The claim of "Evidence for dark matter" on a recent letter to Nature Physics (Iocco, Pato, and Bertone 2015) appears excessive. The authors have convincingly shown that the baryonic matter distribution in our galaxy cannot account for the observed rotation curve of our galaxy, at scales somewhat shorter than those of the $\sim$ 8kpc solar radius. This result extends inwards the inconsistency between the observed baryonic matter and the measured rotation curve, already well known at large radii. Two generic ways to deal with this discrepancy are currently under discussion in the scientific literature (Capozziello and de Laurentis 2011, Famaey and McGaugh 2012, Nojiri and Odintsov 2011, Springel *et al.* 2008): (a) To keep Newton's gravity unchanged and make up any dynamical mismatch through the addition of as much hypothetical non-baryonic dark matter as required. And (b) To search for a modified theory of gravity under which no such discrepancies appear. The latter requires a transition away from Newton's gravitation appearing below acceleration scales (Milgrom 1983) $a_0 \approx 1.2 \times 10^{-10}\ \mathrm{m\,s^{-2}}$.

The figure shows how the discrepancies found by the authors appear at an acceleration scale of order a_0. Also shown in the figure is the expected range of angular frequencies corresponding to the baryonic distribution considered in the letter in question, under a MOdified Newtonian Dynamics (MOND) model. The discrepancy is no longer evident, specially at galactocentric distances smaller than 10kpc, acknowledged by the authors themselves as the high quality data region. Considering various of the MOND interpolation functions proposed in the literature would somewhat broaden the cross shaded region in the above plot, as it is precisely in this transition region -where accelerations are of order a_0- that the various possible interpolation functions differ. We have also not included uncertainties in the empirical calibrations (Gentile, Famaey, and de Blok 2011) of a_0 of $\pm 0.3 \times 10^{-10} \mathrm{m\,s^{-2}}$, since we aim merely to show how the velocity data presented by Iocco, Pato, and Bertone (2015) can be reproduced from the baryonic models these same authors use.

The history of gravitational anomalies extends back to almost 200 years; when reporting on the observed residuals in the orbit of Neptune, Bouvard (1821) correctly concluded that either (i) the effect of the Sun's gravity, at such a great distance might differ from Newton's description, or (ii) the discrepancies might simply be observational error; or (iii) perhaps Uranus was being pulled, or perturbed, by an as-yet undiscovered planet. On that occasion option (iii) proved correct, not so however in the following instance, where the observed peculiarities in the orbit of Mercury turned out not to signal "dark matter", but indeed, marked the end of the validity regime of Newtonian gravity towards high velocities.

It is important to note that the difference between the two points of view is far from merely semantic: both reflect fundamentally distinct ideas of reality, either space is teeming with unseen particles far outnumbering the detectable universe, or it is not. Both lead to distinct predictions in a number of cases, e.g. black hole growth rates will be affected by the accretion of dark matter, or not (Hernandez and Lee 2010). A satellite galaxy orbiting within a dark matter halo will gravitationally interact with countless dark matter particles, loose energy and experience dynamical friction, or it will not (Sánchez-Salcedo, Reyes-Iturbide, and Hernandez 2006). Any theory where the driving causal entity is something no one has ever seen, (e.g. Cartesian vortices, phlogiston, caloric or the electromagnetic aether) should be treated, at best, as a temporary working hypothesis.

In summary, Iocco's (2015) conclusion for "...a convincing proof of the existence of dark matter..." is misleading, specially given that they fail to mention that

* Email address: rdurazo,xavier,sergio@astro.unam.mx

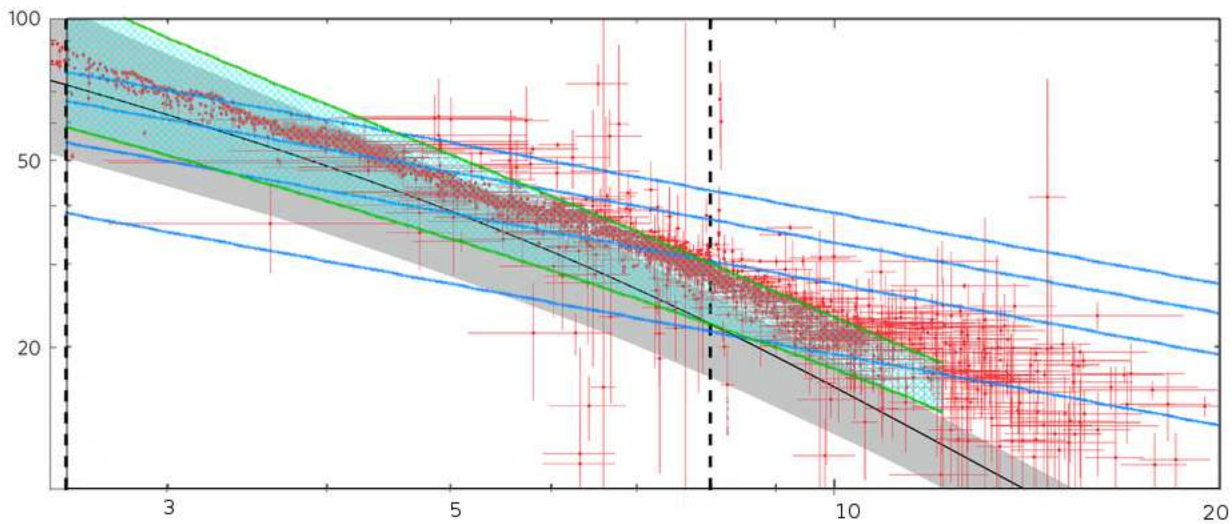

FIG. 1. On the log-log angular frequency vs. galactocentric radius plot of the upper panel from figure (2) of Iocco, Pato, and Bertone (2015), we have superimposed blue curves of constant acceleration $a = a_0,\ 2a_0,\ 3a_0,\ 4a_0$, from bottom to top respectively. The cross shaded region bound in green, shows the angular frequencies which the gray baryonic models of the above authors result in, using a MOND model (Mendoza *et al.* 2011) where the gravitational force per unit mass in units of a_0 is given by $f(x) = \left(x^3 + x^2 + x\right) / (x+1)$, where $x^2 := GM(R)/a_0 R^2$ and G is Newton's gravitational constant, R the galactocentric distance and $M(R)$ the enclosed mass. Note that the Newtonian gravitational regime is recovered for $x \gg 1$.

their analysis is restricted to a small subset amongst the many theories of gravitation currently under consideration in the scientific literature.

Bouvard, A., *Tables Astronomiques Publiees Par Le Bureau Des Longitudes De France, Contenant Les Tables De Jupiter, De Saturne Et D* (Bachelier et Huzard, 1821).

Capozziello, S. and de Laurentis, M., Physics Reports **509**, 167 (2011), arXiv:arXiv:1108.6266 [gr-qc].

Famaey, B. and McGaugh, S. S., Living Reviews in Relativity **15**, 10 (2012), arXiv:arXiv:1112.3960 [astro-ph.CO].

Gentile, G., Famaey, B., and de Blok, W. J. G., Astronomy and Astrophysics **527**, A76 (2011), arXiv:arXiv:1011.4148 [astro-ph.CO].

Hernandez, X. and Lee, W. H., MNRAS **404**, L6 (2010), arXiv:1002.0553 [astro-ph.CO].

Iocco, F., Pato, M., and Bertone, G., Nature Physics (2015), doi:10.1038/nphys3237, advanced online publication, doi:10.1038/nphys3237.

Mendoza, S., Hernandez, X., Hidalgo, J. C., and Bernal, T., MNRAS **411**, 226 (2011), arXiv:arXiv:1006.5037 [astro-ph.GA].

Milgrom, M., Astrophys. J. **270**, 371 (1983).

Nojiri, S. and Odintsov, S. D., Physics Reports **505**, 59 (2011), arXiv:arXiv:1011.0544 [gr-qc].

Sánchez-Salcedo, F. J., Reyes-Iturbide, J., and Hernandez, X., MNRAS **370**, 1829 (2006), astro-ph/0601490.

Springel, V., Wang, J., Vogelsberger, M., Ludlow, A., Jenkins, A., Helmi, A., Navarro, J. F., Frenk, C. S., and White, S. D. M., MNRAS **391**, 1685 (2008), arXiv:arXiv:0809.0898.